

PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re the Application of

Simon TAM

Group Art Unit: 2673

Application No.: 09/899,916

Filed: July 9, 2001

Docket No.: 110031

For: CIRCUIT, DRIVER CIRCUIT, ELECTRO-OPTICAL DEVICE, ORGANIC
ELECTROLUMINESCENT DISPLAY DEVICE ELECTRONIC APPARATUS, METHOD
OF CONTROLLING THE CURRENT SUPPLY TO A CURRENT DRIVEN ELEMENT,
AND METHOD FOR DRIVING A CIRCUIT

CLAIM FOR PRIORITY

Director of the U.S. Patent and Trademark Office
Washington, D.C. 20231

Sir:

The benefit of the filing date of the following prior foreign application filed in the following foreign country is hereby requested for the above-identified patent application and the priority provided in 35 U.S.C. §119 is hereby claimed:

Great Britain Application No. 0016815.3, filed July 7, 2000.

In support of this claim, a certified copy of said original foreign application:


 X is filed herewith.

 was filed on in Parent Application No. filed .

 will be filed at a later date.

It is requested that the file of this application be marked to indicate that the requirements of 35 U.S.C. §119 have been fulfilled and that the Patent and Trademark Office kindly acknowledge receipt of this document.

Respectfully submitted,


James A. Oliff
Registration No. 27,075

Eric D. Morehouse
Registration No. 38,565

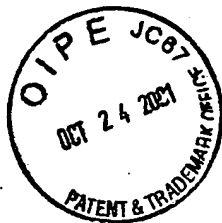
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Date: October 24, 2001

OLIFF & BERRIDGE, PLC
P.O. Box 19928
Alexandria, Virginia 22320
Telephone: (703) 836-6400

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I also certify that the attached copy of the request for grant of a Patent (Form 1/77) bears a correction, effected by this office, following a request by the applicant and agreed to by the Comptroller-General.

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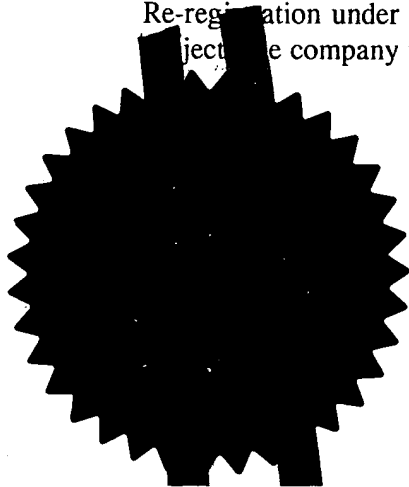
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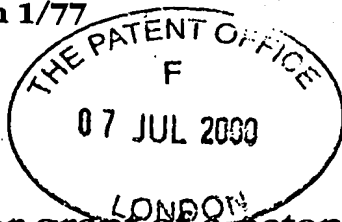
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Request for grant of a patent

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10JUL00 E551429-1 D00328 Patent NP9 1RH
P01/7700 0.00-0016815.3

1. Your reference

GBP13472A

2. Patent application number

(The Patent Office will fill in this part)

0016815.3

07 JUL 2000

3. Full name, address and postcode of the or of each applicant (underline all surnames)

Seiko Epson Corporation
4-1, Nishishinjuku 2-chome,
Shinjuku-ku,
Tokyo 163-0811
Japan

Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

712331003
Tokyo, Japan

4. Title of the invention

ORGANIC ELECTROLUMINESCENT DEVICE
COMPENSATED PIXEL DRIVER CIRCUIT

5. Name of your agent (if you have one)

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

Miller Sturt Kenyon
9 John Street
London WC1N 2ES
United Kingdom

Patents ADP number (if you know it)

07395486001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (if you know it) the or each application number

Country	Priority application number (if you know it)	Date of filing (day / month / year)
UK	0007879.0	31/03/00
NO	23/4/01	11/77 30/8/01

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing (day / month / year)

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Description

11

Claim(s)

4

Abstract

1

Drawing(s)

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Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (Patents Form 7/77)

Request for preliminary examination and search (Patents Form 9/77)

1

Request for substantive examination (Patents Form 10/77)

Any other documents
(please specify)

11. I/We request the grant of a patent on the basis of this application.

Signature

Date

Mille Stuart Kenyon

7th July 2000

12. Name and daytime telephone number of person to contact in the United Kingdom

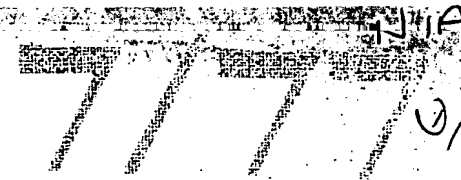
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**Statement of inventorship and of
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1. Your reference

GBP13472A

2. Patent application number
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0016815.3

3. Full name of the or of each applicant

Seiko Epson Corporation

4. Title of the invention

Organic Electroluminescent Device Compensated
Pixel Driver Circuit

5. State how the applicant(s) derived the right
from the inventor(s) to be granted a patent

By virtue of employment

6. How many, if any, additional Patents Forms
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7. I/We believe that the person(s) named over the page (and on
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which the above patent application relates to.

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Date

Michael Sturt Keyson

1st May 2001

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50135 MJC31

Enter the full names, addresses and postcodes of the inventors in the boxes and underline the surnames

Simon TAM
c/o Epson Cambridge Laboratory
8c Kings Parade
Cambridge CB2 1SJ

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7991128001

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Organic ElectroLuminescent Device
Compensated Pixel Driver Circuit

DUPLICATE

The present invention relates to an organic electroluminescent device and particularly to a compensated pixel driver circuit thereof.

An organic electroluminescent device (OELD) consists of a light emitting polymer (LEP) layer sandwiched between an anode layer and a cathode layer. Electrically, this device operates like a diode. Optically, it emits light when forward biased and the intensity of the emission increases with the forward bias current. It is possible to construct a display panel with a matrix of OELDs fabricated on a transparent substrate and with one of the electrode layers being transparent. It is also possible to integrate the driving circuit on the same panel by using low temperature polysilicon thin film transistor (TFT) technology.

In a basic analog driving scheme for an active matrix OELD display, a minimum of two transistors are required per pixel. Such a driving scheme is illustrated in Figure 1. Transistor T_1 is provided to address the pixel and transistor T_2 is provided to convert a data voltage signal V_{Data} into current which drives the OELD at a designated brightness. The data signal is stored by a storage capacitor $C_{Storage}$ when the pixel is not addressed. Although p-channel TFTs are shown in the figure, the same principle can also be applied for a circuit utilising n-channel TFTs.

There are problems associated with TFT analog circuits and OELDs do not act like perfect diodes. The LEP material does, however, have relatively uniform characteristics. Due to the nature of the TFT fabrication technique, spatial variation of the TFT characteristics exists over the extent of the display panel. One of the most important considerations in a TFT analog circuit is the variation of threshold voltage, ΔV_T , from

device to device. The effect of such variation in an OLED display, exacerbated by the non perfect diode behaviour, is the non-uniform pixel brightness over the display area of the panel, which seriously affects the image quality. Therefore, a built-in compensation circuit is required.

A simple threshold voltage variation compensation, current driven, circuit has been proposed. The current driven circuit, also known as the current programmed threshold voltage compensation circuit, is illustrated in figure 2. In this circuit, transistor T_1 is provided for addressing the pixel. Transistor T_2 operates as an analog current control to provide the driving current to the OLED. Transistor T_3 connects between the drain and gate of transistor T_2 and toggles transistor T_2 to act either as a diode or in a saturation mode. Transistor T_4 acts as a switch in response to an applied waveform V_{GP} . Either Transistor T_1 or transistor T_4 can be ON at any one time. Initially, at time t_0 shown in the timing diagram of Figure 2, transistors T_1 and T_3 are OFF, and transistor T_4 is ON. When transistor T_4 is OFF, transistors T_1 and T_3 are ON, and a current I_{DAT} of known value is allowed to flow into the OLED, through transistor T_2 . This is the programming stage because the threshold voltage of transistor T_2 is measured with transistor T_3 turned ON which shorts the drain and gate of transistor T_2 . Hence transistor T_2 operates as a diode while the programming current is allowed to flow through transistors T_1 and T_2 and into the OLED. The detected threshold voltage of transistor T_2 is stored by a capacitor C_1 connected between the gate and source terminals of transistor T_2 when transistors T_3 and T_1 are switched OFF. Transistor T_4 is then turned ON by driving waveform V_{GP} and the current through the OLED is now provided by supply V_{DD} . If the slope of the output

characteristics for transistor T_2 were flat, the reproduced current would be the same as the programmed current for any threshold voltage of T_2 detected and stored in capacitor C_1 . However, by turning ON transistor T_4 , the drain-source voltage of transistor T_2 is pulled up, so a flat output characteristic will maintain the reproduced current at the same level as the programmed current. Note that ΔV_{T2} shown in figure 2 is imaginary, not real. It has been used solely to represent the threshold voltage of transistor T_2 .

A constant current is provided, in theory, during a subsequent active programming stage, which is signified by the time interval t_2 to t_5 in the timing diagram shown in figure 2. The reproduction stage starts at time t_6 .

The circuit of Figure 2 does provide an improvement over the circuit shown in Figure 1 but variations in the threshold value of the control transistor are not fully compensated and variations in image brightness over the display area of the panel remain.

The present invention seeks to provide, therefore, an improved compensated pixel driver circuit in which variations in the threshold voltages of the pixel driver transistor can be further compensated, thereby providing a more uniform pixel brightness over the display area of the panel and, therefore, improved image quality.

According to a first aspect of the present invention there is provided a compensated pixel driver circuit for an electroluminescent device, the circuit comprising an n-channel transistor and a complementary p-channel transistor connected so as to operatively control, in combination, the current supplied to the electroluminescent device.

Preferably, the compensated pixel driver circuit also comprises respective storage capacitors for the n-channel and p-channel transistors and respective switching means

connected so as to establish when operative respective paths to the n-channel and p-channel transistors for respective data voltage pulses.

Advantageously, the compensated pixel driver circuit may also comprise respective storage capacitors for storing a respective operating voltage of the n-channel and the p-channel transistors during a programming stage, a first switching means connected so as to establish when operative a first current path from a source of current data signals through the n-channel and p-channel transistors and the electroluminescent device during the programming stage, and a second switching means connected to establish when operative a second current path through the n-channel and p-channel transistors and the electroluminescent device during a reproduction stage.

In a further embodiment, the first switching means and the source of current data signals are connected so as to provide when operative a current source for the electroluminescent device

In an alternative embodiment, the first switching means the source of current data signals are connected so as to provide when operative a current sink for the electroluminescent device.

According to a second aspect of the present invention there is also provided a method of compensating the supply current to an electroluminescent device comprising providing an n-channel transistor and a p-channel transistor connected so as to operatively control, in combination, the supply current to the electroluminescent device.

Preferably, the method further comprises providing respective storage capacitors for the n-channel and p-channel transistors and respective switching means connected so as to establish when operative respective paths to the n-channel and p-channel transistors for

respective data voltage pulses thereby to establish, when operative, a voltage driver circuit for the electroluminescent device.

Advantageously, the method may comprise providing a programming stage during which the n-channel and p-channel transistors are operated in a first mode and wherein a current path from a source of current data signals is established through the n-channel and the p-channel transistors and the electroluminescent device and wherein a respective operating voltage of the n-channel transistor and the p-channel transistor is stored in respective storage capacitors, and a reproduction stage wherein a second mode and a second current path is established through the n-channel transistor and the p-channel transistor and the electroluminescent device.

According to a third aspect of the present invention, there is also provided an organic electroluminescent display device comprising a compensated pixel driver circuit as claimed in any one of claims 1 to 11.

The present invention will now be described by way of further example only, with reference to the accompanying drawings in which:-

Fig. 1 shows a conventional OLED pixel driver circuit using two transistors;

Fig. 2 shows a known current programmed OLED driver circuit with threshold voltage compensation;

Fig. 3 illustrates the concept of a compensated pixel driver circuit including a complementary pair of driver transistors for providing threshold voltage compensation in accordance with the present invention;

Fig. 4 shows plots of characteristics for the complementary driver transistors illustrated in Fig. 3 for various levels of threshold voltages;

Fig. 5 shows a compensated pixel driver circuit arranged to operate as a voltage driver circuit in accordance with a first embodiment of the present invention.

Fig. 6 shows a compensated pixel driver circuit arranged to operate as a current programmed driver circuit in accordance with a second embodiment of the present invention;

Fig. 7 shows a compensated current programmed driver circuit in accordance with a third embodiment of the present invention, and

Figs 8 to 11 show SPICE simulation results for the circuit illustrated in Fig. 6.

The concept of a compensated pixel driver circuit according to the present invention is illustrated in Fig. 3. An OLED device is coupled between two transistors T_{11} and T_{12} which operate, in combination, as an analog current control for the current flowing through the OLED. Transistor T_{11} is a p-channel transistor and transistor T_{12} is an n-channel transistor which act therefore, in combination, as a complementary pair for analog control of the current through the OLED.

As mentioned previously, one of the most important parameters in a TFT analog circuit design is the threshold voltage V_T . Any variation, ΔV_T within a circuit has a significant effect on the overall circuit performance. Variations in the threshold voltage can be viewed as a rigid horizontal shift of the source to drain current versus the gate to source voltage characteristic for the transistor concerned and are caused by the interface charge at the gate of the transistor.

It has been realised with the present invention that in an array of TFT devices, in view of the fabrication techniques employed, neighbouring or relatively close TFT's have a high probability of exhibiting the same or an almost similar value of threshold voltage ΔV_T . Furthermore, it has been realised that as the effects of the same ΔV_T on p-channel and n-

channel TFT's are complementary, compensation for variations in threshold voltage ΔV_T can be achieved by employing a pair of TFT's, one p-channel TFT and one n-channel TFT, to provide analog control of the driving current flowing to the OLED. The driving current can, therefore, be provided independently of any variation of the threshold voltage. Such a concept is illustrated in figure 3.

Figure 4 illustrates the variation in drain current, that is the current flowing through the OLED shown in figure 3, for various levels of threshold voltage ΔV_T , ΔV_{T1} , ΔV_{T2} for the transistors T_{11} and T_{12} . Voltages V_1 , V_2 and V_D are respectively the voltages appearing across transistor T_{11} , T_{12} and the OLED from a voltage source V_{DD} . Assuming that the transistors T_{11} and T_{12} have the same threshold voltage and assuming that $\Delta V_T = 0$, then the current flowing through the OLED is given by cross-over point A for the characteristics for the p-channel transistor T_{11} and the n-channel transistor T_{12} shown in figure 4. This is shown by value I_0 .

Assuming now that the threshold voltage of the p-channel and n-channel transistors changes to ΔV_{T1} , the OLED current I_1 is then determined by crossover point B. Likewise, for a variation in threshold voltage to ΔV_2 , the OLED current I_2 is given by crossover point C. It can be seen from figure 4 that even with the variations in the threshold voltage there is minimal variation in the current flowing through the OLED.

Figure 5 shows a compensated pixel driver circuit configured as a voltage driver circuit. The circuit comprises p-channel transistor T_{12} and n-channel transistor T_{15} acting as a complementary pair to provide, in combination, an analog current control for the OLED. The circuit includes respective storage capacitors C_{12} and C_{15} and respective switching transistors T_A and T_B coupled to the gates of transistors T_{12} and T_{15} . When transistors T_A and

T_B are switched ON data voltage signals V_1 and V_2 are stored respectively in storage capacitors C_{12} and C_{15} when the pixel is not addressed. The transistors T_A and T_B function as pass gates under the selective control of addressing signals ϕ_1 and ϕ_2 applied to the gates of transistors T_A and T_B .

Figure 6 shows a compensated driver circuit according to the present invention configured as a current programmed OELD driver circuit. As with the voltage driver circuit, p-channel transistor T_{12} and n-channel transistor T_{15} are coupled so as to function as an analog current control for the OELD. Respective storage capacitors C_1 , C_2 and respective switching transistors T_1 and T_6 are provided for transistors T_{12} and T_{15} . The driving waveforms for the circuit are also shown in figure 6. Either transistors T_1 , T_3 and T_6 , or transistor T_4 can be ON at any one time. Transistors T_1 and T_6 connect respectively between the drain and gate of transistors T_{12} and T_{15} and switch in response to applied waveform V_{SEL} to toggle transistors T_{12} and T_{15} to act either as diodes or as transistors in saturation mode. Transistor T_3 is also connected to receive waveform V_{SEL} . Transistors T_1 and T_6 are both p-channel transistors to ensure that the signals fed through these transistors are at the same magnitude. This is to ensure that any spike currents through the OELD during transitions of the waveform V_{SEL} are kept to a minimum.

The circuit shown in figure 6 operates in a similar manner to known current programmed pixel driver circuits in that a programming stage and a display stage are provided in each display period but with the added benefit that the drive current to the OELD is controlled by the complementary opposite channel transistors T_{12} and T_{15} . Referring to the driving waveforms shown in figure 6, a display period for the driver circuit extends from time t_0 to time t_6 . Initially, transistor T_4 is ON and transistors T_1 , T_3 and T_6 are OFF. Transistor T_4 is turned OFF at time t_1 by the waveform V_{GP} and transistors T_1 , T_3

and T_6 are turned ON at time t_3 by the waveform V_{SEL} . With transistors T_1 and T_6 turned ON, the p-channel transistor T_{12} and the complementary n-channel transistor T_{15} act in a first mode as diodes. The driving waveform for the frame period concerned is available from the current source I_{DAT} at time t_2 and this is passed by the transistor T_3 when it switches on at time t_3 . The detected threshold voltages of transistors T_{12} and T_{15} are stored in capacitors C_1 and C_2 . These are shown as imaginary voltage sources ΔV_{T12} and ΔV_{T15} in figure 6.

Transistors T_1 , T_3 and T_6 are then switched OFF at time t_4 and transistor T_4 is switched ON at time t_5 and the current through the OLED is then provided from the source VDD under the control of the p-channel and n-channel transistors T_{12} and T_{15} operating in a second mode, i.e. as transistors in saturation mode. It will be appreciated that as the current through the OLED is controlled by the complementary p-channel and n-channel transistors T_{12} and T_{15} , any variation in threshold voltage in one of the transistors will be compensated by the other opposite channel transistor, as described previously with respect to figure 4.

In the current programmed driver circuit shown in figure 6, the switching transistor T_3 is coupled to the p-channel transistor T_{12} , with the source of the driving waveform I_{DAT} operating as a current source. However, the switching transistor T_3 may as an alternative be coupled to the n-channel transistor T_{15} as shown in figure 7, whereby I_{DAT} operates as a current sink. In all other respects the operation of the circuit shown in figure 7 is the same as for the circuit shown in figure 6.

Figures 8 to 11 show a SPICE simulation of an improved compensated pixel driver circuit according to the present invention.

Referring to figure 8, this shows the driving waveforms I_{DAT} , V_{GP} , V_{SEL} and three values of threshold voltage, namely -1volt, 0volts and +1volt used for the purposes of simulation to show the compensating effect provided by the combination of the p-channel and n-channel transistors for controlling the current through the OELD. From figure 8, it can be seen that, initially the threshold voltage ΔV_T was set at -1volt, increasing to 0volts at 0.3×10^{-4} seconds and increasing again to +1volt at 0.6×10^{-4} seconds. However, it can be seen from figure 9 that even with such variations in the threshold voltage the driving current through the OELD remains relatively unchanged.

The relative stability in the driving current through the OELD can be more clearly seen in figure 10, which shows a magnified version of the response plots shown in figure 9.

It can be seen from figure 10 that, using a value of 0 volts as a base for the threshold voltage ΔV_T , that if the threshold voltage ΔV_T changes to -1volts there is a change of approximately 1.2% in the drive current through the OELD and if the threshold voltage ΔV_T is changed to +1volt, there is a reduction in drive current of approximately 1.7% compared to the drive current when the threshold voltage ΔV_T is 0 volts. The variation of drive current of 8.7% is shown for reference purposes only as such a variation can be compensated by gamma correction, which is well known in this art and will not therefore be described in relation to the present invention.

Figure 11 shows that for levels of I_{DAT} ranging from $0.2\mu A$ to $1.0\mu A$, the improved control of the OELD drive current is maintained by the use of the p-channel and opposite n-channel transistors in accordance with the present invention.

It will be appreciated from the above description that the use of a p-channel transistor and an opposite n-channel transistor to provide, in combination, analog control of

the drive current through an electroluminescent device provides improved compensation for the effects which would otherwise occur with variations in the threshold voltage of a single p-channel or n-channel transistor.

Preferably, the TFT n-channel and p-channel transistors are fabricated as neighbouring or adjacent transistors during the fabrication of an OLED display so as to maximise the probability of the complementary p-channel and n-channel transistors having the same value of threshold voltage ΔV_T . The p-channel and n-channel transistors may be further matched by comparison of their output characteristics.

The improved compensated pixel driver circuit of the present invention may be used in display devices incorporated in many types of equipment such as mobile displays e.g. mobile phones, laptop personal computers, DVD players, cameras, field equipment; portable displays such as desktop computers, CCTV or photo albums; or industrial displays such as control room equipment displays.

The foregoing description has been given by way of example only and it will be appreciated by a person skilled in the art that modifications can be made without departing from the scope of the present invention.

CLAIMS

1. A compensated pixel driver circuit for an electroluminescent device, the circuit comprising an n-channel transistor and a complementary p-channel transistor connected so as to operatively control, in combination, the current supplied to the electroluminescent device.
2. A compensated pixel driver circuit as claimed in claim 1, wherein the complementary n-channel and p-channel transistors comprise polysilicon thin film transistors.
3. A compensated pixel driver circuit as claimed in claim 2, wherein the complementary n-channel and p-channel transistors are spatially arranged in close proximity to each other for providing a complementary pair of n-channel and p-channel transistors having approximately equal threshold voltages.
4. A compensated pixel driver circuit as claimed in any one of claims 1 to 3 connected so as to establish when operative a voltage driver circuit comprising respective storage capacitors for the n-channel and p-channel transistors and respective switching means connected so as to establish when operative respective paths to the n-channel and p-channel transistors for respective data voltage pulses.

5. A compensated pixel driver circuit as claimed in any one of claims 1 to 3 comprising respective storage capacitors for storing a respective operating voltage of the n-channel and the p-channel transistors during a programming stage, a first switching means connected so as to establish when operative a first current path from a source of current data signals through the n-channel and p-channel transistors and the electroluminescent device during the programming stage, and a second switching means connected to establish when operative a second current path through the n-channel and p-channel transistors and the electroluminescent device during a reproduction stage.
6. A compensated pixel driver circuit as claimed in claim 5, wherein the first switching means and the source of current data signals are connected so as to provide when operative a current source for the electroluminescent device.
7. A compensated pixel driver circuit as claimed in claim 5, wherein the first switching means and the source of current data signals are connected so as to provide when operative a current sink for the electroluminescent device.
8. A compensated pixel driver circuit as claimed in any one of claims 5 to 7, further comprising respective further switching means respectively connected to bias the n-channel transistor and the p-channel transistor to act as diodes during the programming stage.
9. A compensated pixel driver circuit as claimed in claim 8, wherein the respective further switching means comprise p-channel transistors.

10. A compensated pixel driver circuit as claimed in any one of claims 5 to 9, wherein the circuit is implemented with polysilicon thin film transistors.
11. A compensated pixel driver circuit as claimed in claim 4, wherein the circuit is implemented using polysilicon thin film transistors.
12. A method of compensating the supply current to an electroluminescent device comprising providing an n-channel transistor and a p-channel transistor connected so as to operatively control, in combination, the supply current to the electroluminescent device.
13. A method as claimed in claim 11, comprising the further step of providing the n-channel transistor and the p-channel transistor as polysilicon thin film transistors.
14. A method as claimed in claim 12 comprising the further step of spatially arranging the n-channel and p-channel polysilicon thin film transistors in close proximity to each other.
15. A method as claimed in any one of claims 12 to 14 comprising providing respective storage capacitors for the n-channel and p-channel transistors and respective switching means connected so as to establish when operative respective paths to the n-channel and p-channel transistors for respective data voltage pulses thereby to establish, when operative, a voltage driver circuit for the electroluminescent device.

16. A method as claimed in any one of claims 12 to 14 comprising providing a programming stage during which the n-channel and p-channel transistors are operated in a first mode and wherein a current path from a source of current data signals is established through the n-channel and the p-channel transistors and the electroluminescent device and wherein a respective operating voltage of the n-channel transistor and the p-channel transistor is stored in respective storage capacitors, and a reproduction stage wherein a second mode and a second current path is established through the n-channel transistor and the p-channel transistor and the electroluminescent device.

17. A method as claimed in claim 15, wherein the first mode comprises operating the n-channel and p-channel transistors as diodes.

18. An organic electroluminescent display device comprising a compensated pixel driver circuit as claimed in any one of claims 1 to 11.

ABSTRACT

Organic ElectroLuminescent Device
Compensated Pixel Driver Circuit

A compensated pixel driver circuit comprises a p-channel transistor and an n-channel transistor connected as a complementary pair of transistors to provide analog control of the drive current for an organic electroluminescent device (OELD). The transistors, being of opposite channel, compensate for any variation in threshold voltage ΔV_T and therefore provide a drive current to the OELD which is relatively independent of ΔV_T . The complementary pair of transistors can be applied to either voltage driving or current driving pixel driver circuits.

Figure 7

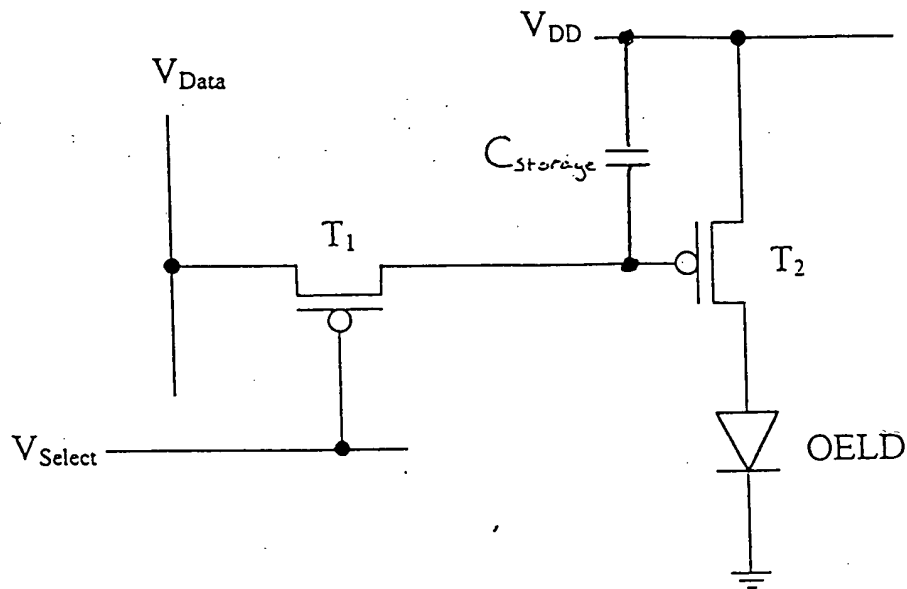


Figure 1

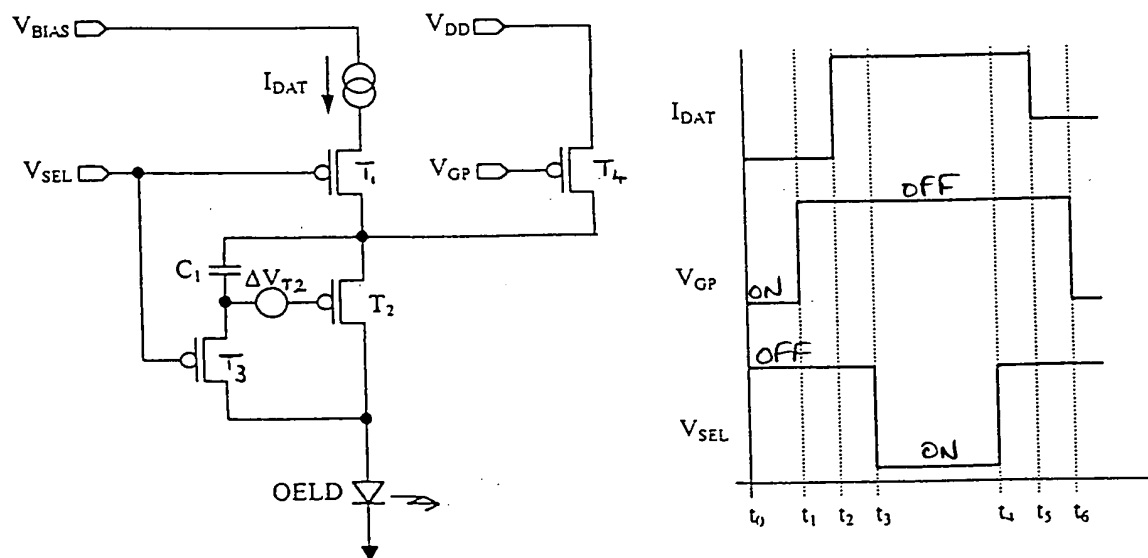


Figure 2

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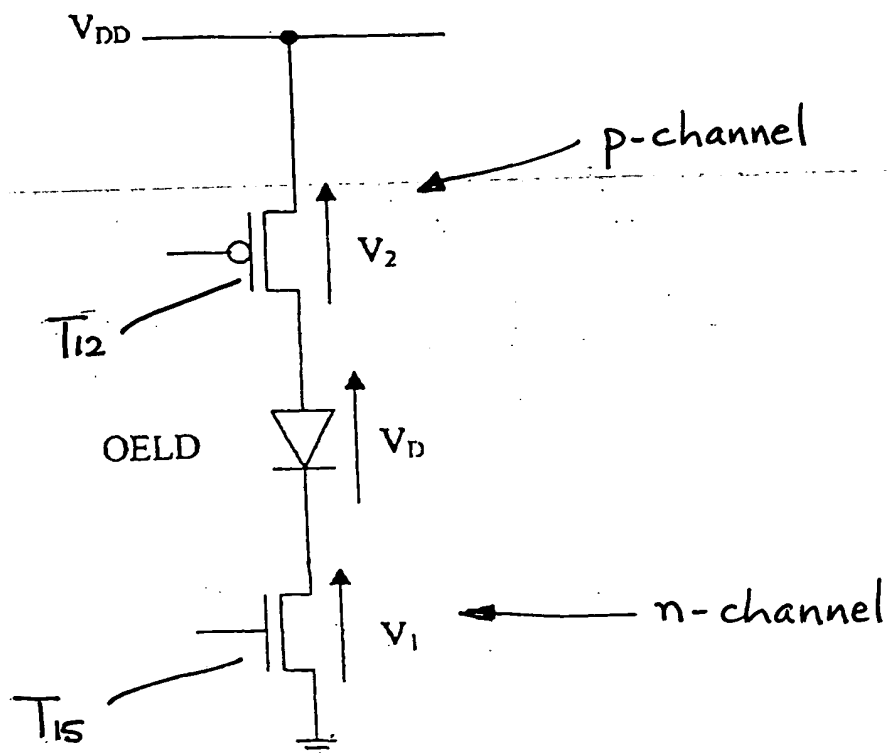


FIGURE 3

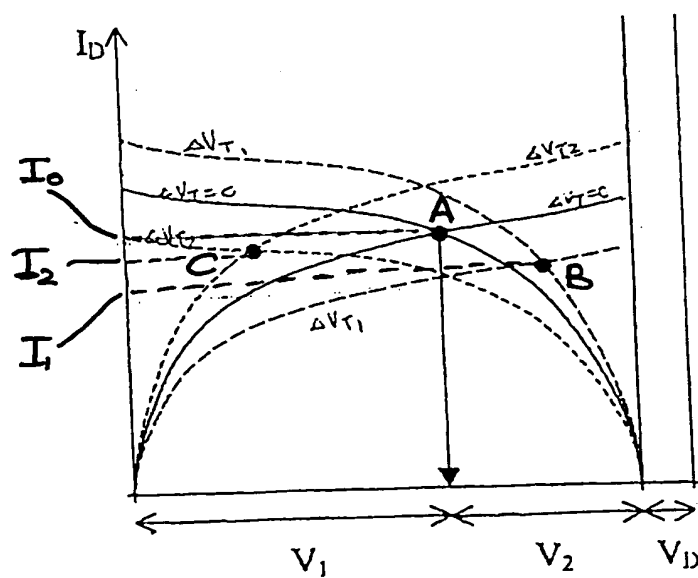


FIGURE 4

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Data
Voltages

V_1 V_2

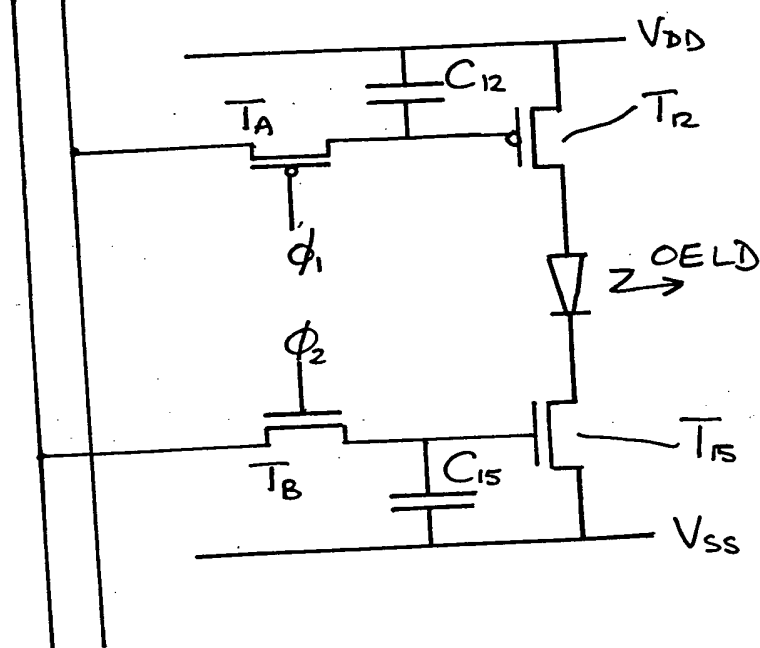


FIGURE 5

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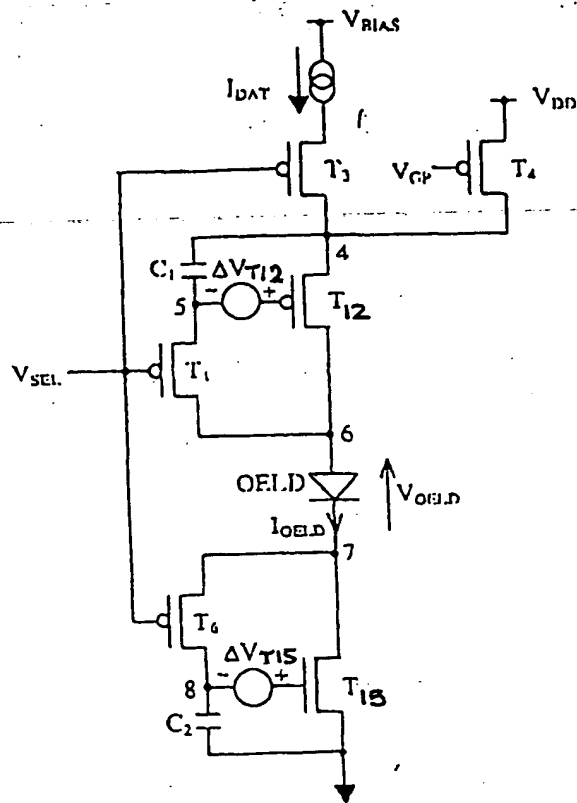
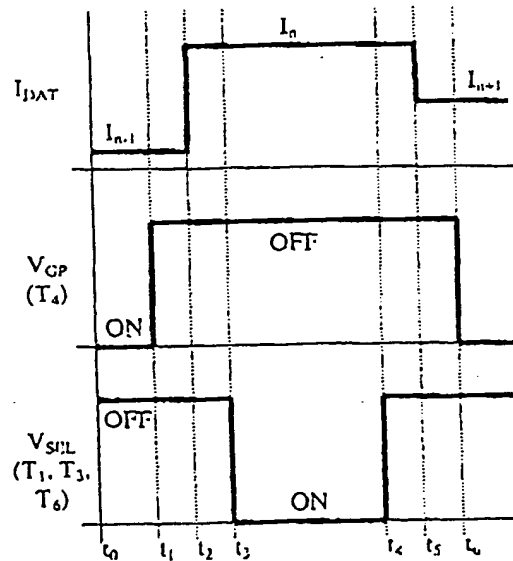


FIGURE 6

Driving Waveform



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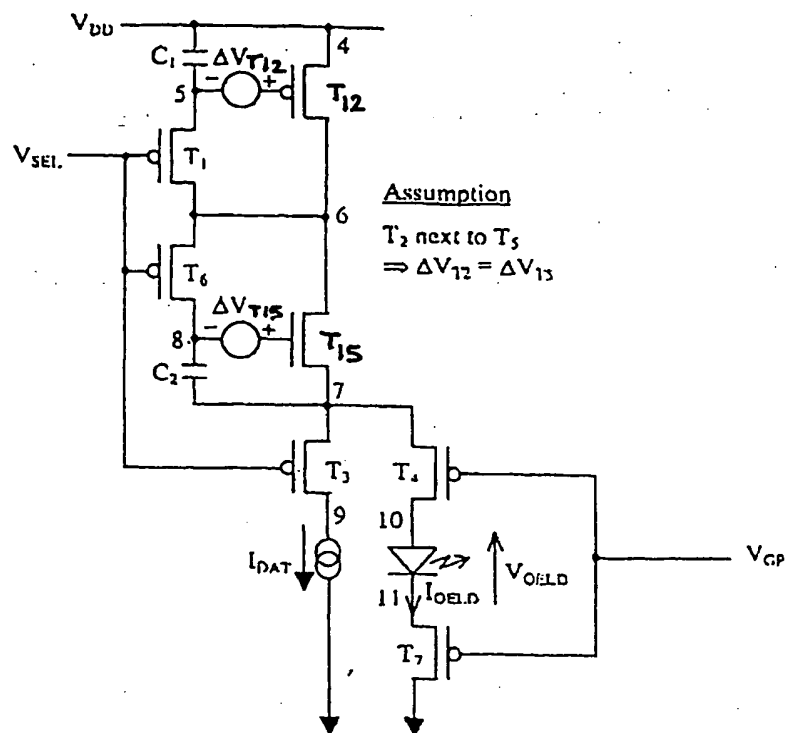
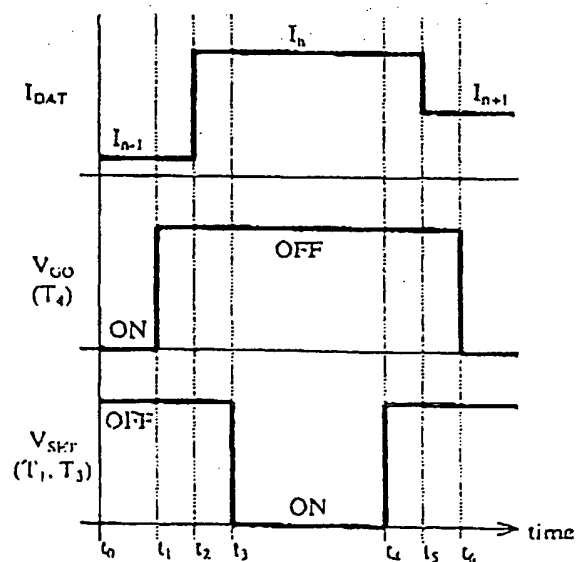


FIGURE 7



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SPICE Simulation Result

($V_{DD} = 12.5V$, $I_{DAT} = 1\mu A$)

FIGURE 8

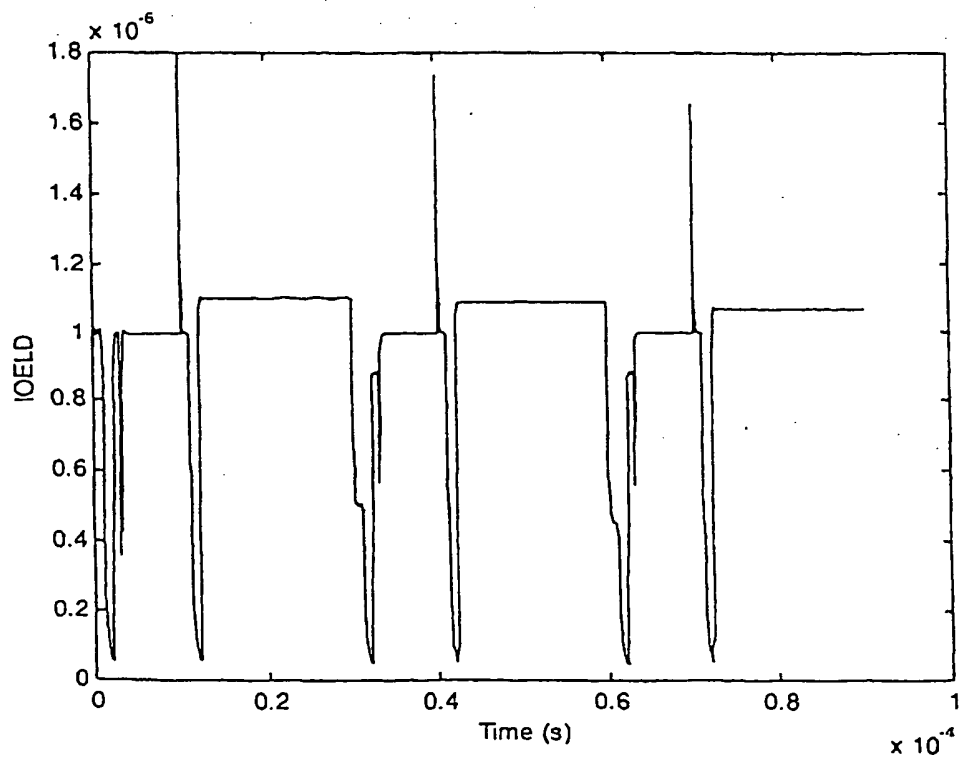
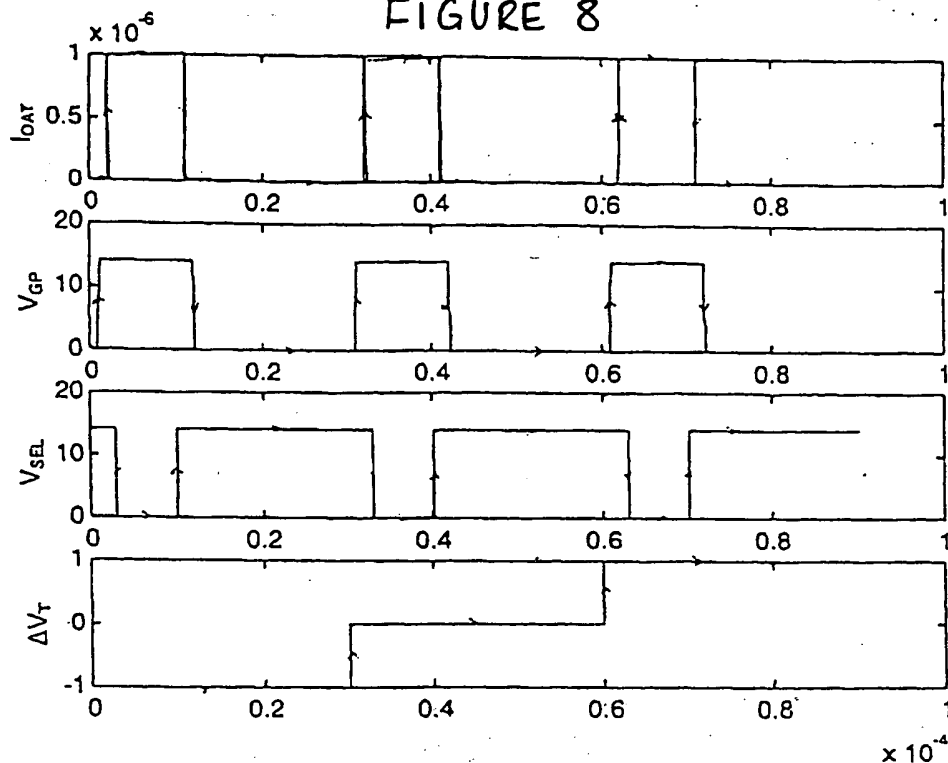


FIGURE 9

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Magnified I_{OELD} Response

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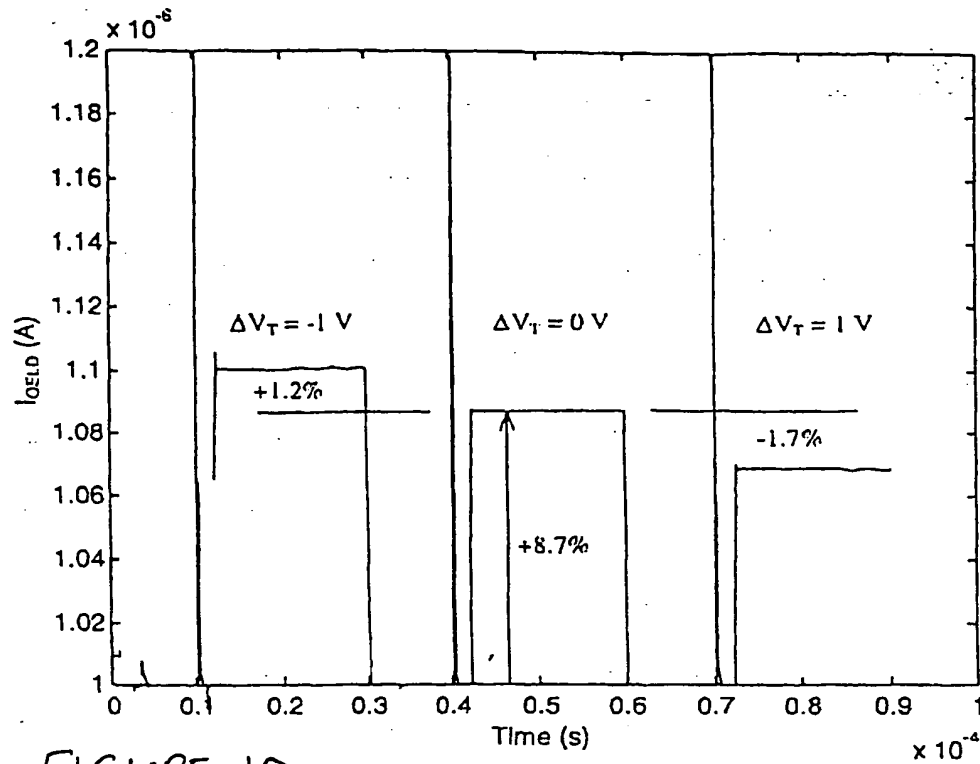


FIGURE 10

I_{OELD} for $I_{DAT} = 0.2\mu\text{A}$ to $1\mu\text{A}$

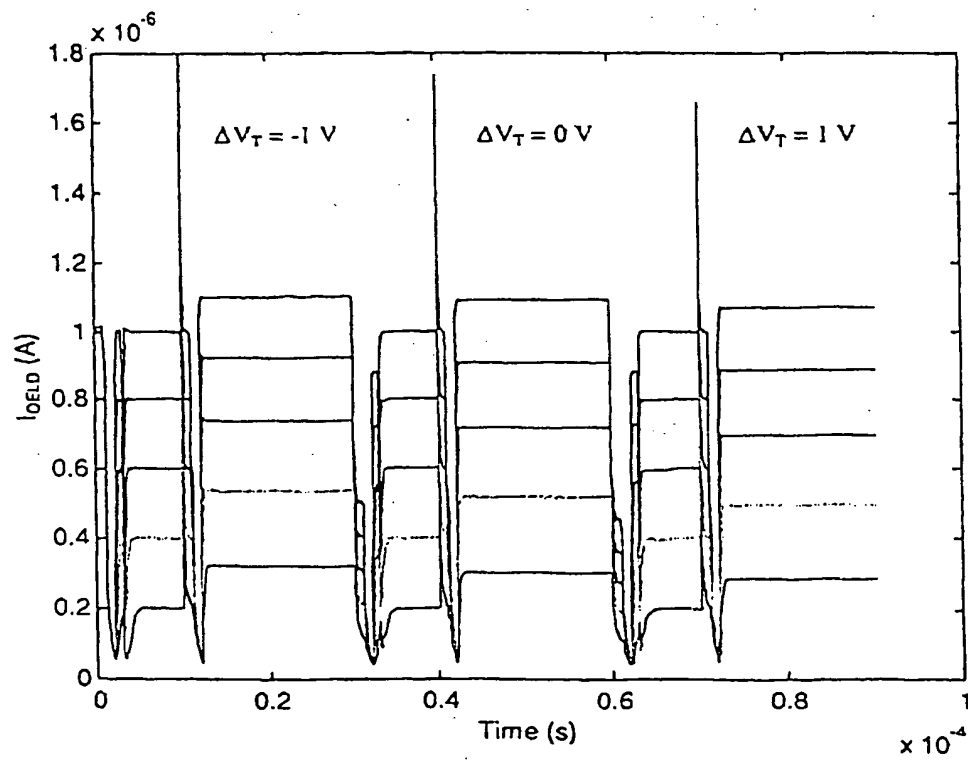


FIGURE 11

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